SOLUTIONAL CAVE PASSAGES INTERSECTED BY MASS MOVEMENT RIFTS IN THE ISLE OF PORTLAND, DORSET

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SUMMARY

The Isle of Portland has long been recognised as an area containing a number of short caves. The recently surveyed Blacknor Hole consists of phreatic passages with some vadose downcutting. They intersect some rifts which have formed along pre-existing joints where the two sides of each joint have separated and moved apart unaided by solutional processes. Immediately behind the cliff at Blacknor these rifts seem to be involved in a natural process of cliff retreat, but it is less clear how those in the centre of the Isle of Portland have widened. Blacknor Hole provides a unique conjunction of water-formed and mass movement passages.

INTRODUCTION

It has long been recognised that deductions about the manner in which a cave passage was formed can be made, based on the shape of the passage as seen in cross-section, and upon forms and features found on the roof, walls and floor. Perhaps the most influential distinction was that made by J. Harlen Bretz (1942) between 'phreatic' and 'vadose' cave passages. More recently, characteristic shapes and forms have been identified indicating that a passage has formed by mechanical separation of its walls, not by solution in water (see Cooper (1983b) for a review). Inferences of these types have led the present authors to conclude that at Blacknor, on the western side of the Isle of Portland, ancient phreatic tubes have been intersected by later 'mass movement' passages.

CAVE PASSAGE TYPES

A thorough and detailed classification system of cave passage types is not attempted here. The intention is to give enough detail for our deductions on the Isle of Portland to be understood.

Phreatic passages

A phreatic passage is one deemed to have developed *below* the water table (also known as the phreatic surface, or simply the phreas). Such a passage will have formed entirely in waterlogged rock, and throughout development will have been at all times full of water, leading to a characteristic sub-circular cross-sectional shape. Most often, phreatic passages also show evidence of structural control of shape: where weaknesses exist in the rock, these may be dissolved differentially by the water, for example along the line of a joint or a bedding plane. By common consent, it is usually possible to tell that the original cave passage was phreatic before or during such modification, because enough of the original cross section remains and is often the part of the cross section roomy enough to permit access by cavers.

Vadose passages

Although they will have originated as phreatic passages, below the water table, vadose passages are deemed to have a cross section which has been substantially modified by water flowing *above* the water table. Such modifications result when a cave passage has not been full of water (except, perhaps, in occasional flood conditions) so that the water flowing through it has had a air-space above the flowing water. This has two effects:

- Calcite formations like stalactites, stalagmites, curtains, flowstone form in the air space. Because the below sea-level water-filled passages in the 'blue holes' of the Bahamas have been observed by divers to contain stalagmites (Farr & Palmer 1984), it is known that at some time they were above sea level, the stalagmites having been formed in air, not water.
- As water flows along the floor of the passage, its chemical erosive activity is perforce concentrated there. This leads to the development of a trench in the floor of the formerly phreatic passage, so that overall, the passage has a 'keyhole' shape. This shape is so characteristic that it is generally used as diagnostic of a vadose passage. However it is important to reiterate that a vadose passage is generally a modification of a phreatic passage.

These ideas have been challenged by the recognition that permeable rocks like limestones frequently have thin impermeable horizons within them, often narrow bands of clay. They are generally of limited lateral extent. They cause local 'perched' water tables above them which can give rise to passages with phreatic features developing well above the ultimate, continuous water table. It has been suggested that the distinction should be made not between passages formed above ('vadose') or below ('phreatic') the water table, but between those formed by water under pressure (giving 'phreatic' features) and those formed by water which is not under pressure (giving 'vadose' features).

Mass movement passages

Characteristically, the passages of mass movement caves, being essentially joints which have widened for some reason, are high and narrow in cross-section. They consist of straight segments of passage, with abrupt corners where the passage changes direction. The walls are often vertical or nearly so. They often contain large fallen blocks of rock wedged at various levels between the walls. At some bedding planes, ledges on one of the walls may have formed; they tend to be mirrored by corresponding overhangs at the same bedding planes on the opposite wall. Likewise, protrusions on one wall tend to be mirrored by matching hollows or 'sockets' on the opposite wall. Undoubtedly, if the walls could be brought together, they would fit. It is apparent that the walls were once together, and the joint along which the passage now runs has opened to such an extent that it is possible for cavers to enter it. Characteristically, enterable mass movement caves are roofed-over, either by debris which has fallen-in and become wedged, or by a 'step' in the fissure, or because the strata near the surface were not involved in the widening movement. Mass movement passages do not possess the features characteristic of solutional or water-worn caves, although flowstone deposits on the walls are quite common.

CAVES IN THE ISLE OF PORTLAND

The Isle of Portland is not really an island, as it is connected to the mainland by a shingle spit, called Chesil Beach. The 'Isle' is therefore technically a 'tombolo'. It is, however, geologically distinct from the mainland. The Weymouth lowland is structurally complex, having been affected by one of the outer ripples of the Alpine mountain-building movements. The results of these movements are most clearly displayed in the 'Lulworth Crumple', which is to be seen at Stair Hole, beside Lulworth Cove on the Dorset coast. At Weymouth a large upfold of the strata took place (the 'Weymouth anticline'), and the Isle of Portland is the only above-sea-level remnant of the southern limb of this. Precise reasons for the Isle's survival are not known, but it seems likely that the Chesil Beach itself, the predominant wave direction and regime, and the local resistance to erosion of the Purbeck and Portland limestones (Jurassic) have been influential.

The existence of caves on the Isle of Portland is quite well known. Gray (1861) found many fissures on the Isle, containing bones, but the fissures can no longer be identified on the ground, and the bones are distributed among many museums. The entire Isle is traversed by NNE-SSW trending joints (Coombe 1981), many of which have been mechanically widened by slipping, presumably on the underlying Kimmeridge Clay, although slipping on some impermeable horizon within the limestones cannot be ruled out, as none of the widened joints can be explored to a definite vertically terminating floor. All the actual floors found in the joints consist of fallen boulders and other debris, and so could be 'false' floors,

with the widened joint continuing downwards below them. Even if a 'floor' could be found, it would be difficult to show that it was not merely a lateral 'step' in the widened joint.

Surveys of the caves have been undertaken by Ford & Hooper (1964) whose map shows eleven named caves on the Isle, and by Churcher, Butler and Bartlett who add five more to the same map (1970). Exploration still continues, and has led to two important discoveries: Sandy Hole and Blacknor Hole, both in the cliff on the western side of the Isle (Fig.1). Sandy Hole, about 2 m above the foot of the vertical 30 m cliff, was reported by Graham & Ryder (1983) as containing both water-worn solutional passages, and some enterable widened joints. Nearby, Blacknor Hole has been explored (named after Blacknor Fort which is in the vicinity). This begins at a hole in the cliff about 12 m down from the clifftop. Although it has been entered using ladders, the usual method of access is a very exposed 12 m abseil from the clifftop, followed by 'penduluming' into the cave entrance.

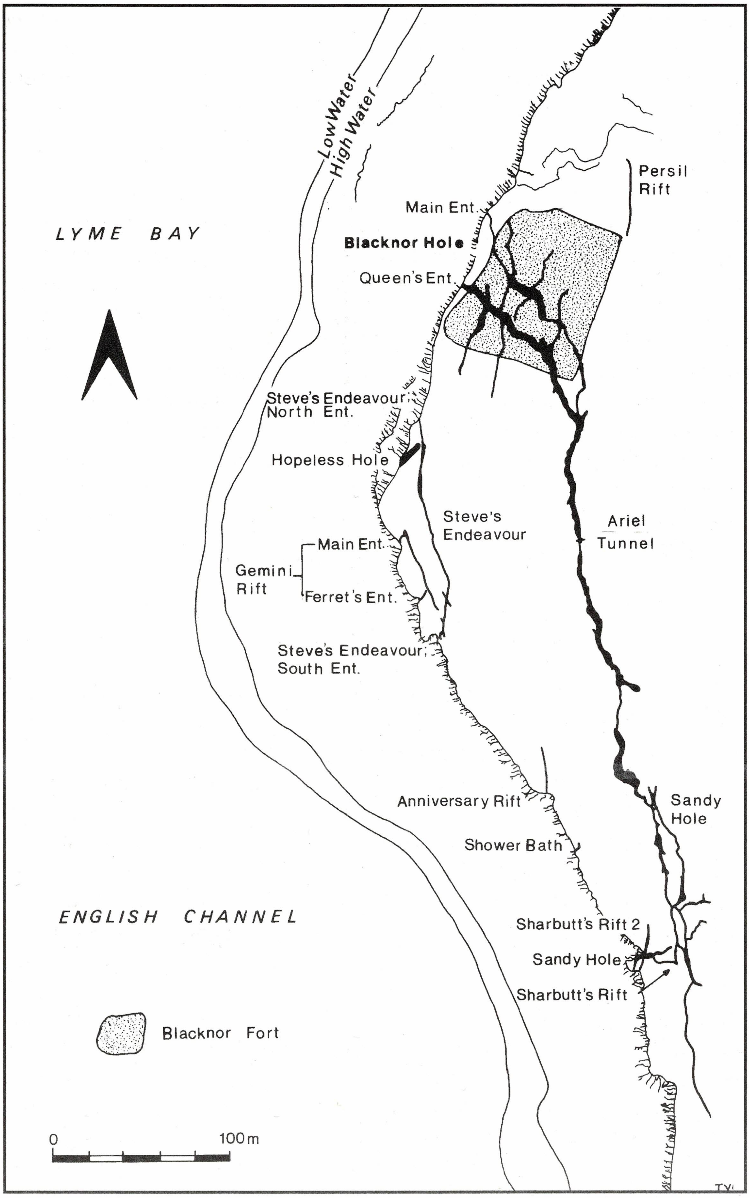

Fig. 1. The caves at Blacknor, Isle of Portland.

BLACKNOR HOLE

At about 957 m, this is by far the longest cave found in the Isle of Portland. A recent development has been the finding of a link to Sandy Hole, permitting a through trip for the intrepid. The combined Blacknor Hole - Sandy Hole system has an overall length of 1359 m while the shortest entrance-to-entrance route is 475 m.

Blacknor Hole begins at the cliff face as two phreatic tubes which meet at a point 90 m orthogonally back from the cliff face (Fig. 2), and continues as a single phreatic passage named Ariel Tunnel, for a further 230 m before the previously-known extent of Sandy Hole is reached. Graham & Ryder (1983) reported that the long passages in Sandy Hole have roofs indicative of phreatic development, but the walls and floors are typical vadose trenches. The effect becomes more pronounced from north to south. The closer one gets to Sandy Hole in Blacknor Hole, the more signs there are of vadose cutting into the floor of the original phreatic tube. At the end of Ariel Tunnel, a vadose passage continues on through Sandy Hole for a further 214 m until further access is terminated by a boulder ruckle. Ariel Tunnel was discovered and extended over a long period of time, by boys from Hardye's School, Dorchester in the early 1970s, by members of Weymouth and Portland Venture Scouts, latterly under the leadership of Mike Read, and by members of the Dorset Caving Group, notably Mike MacTavish and Nigel Graham.

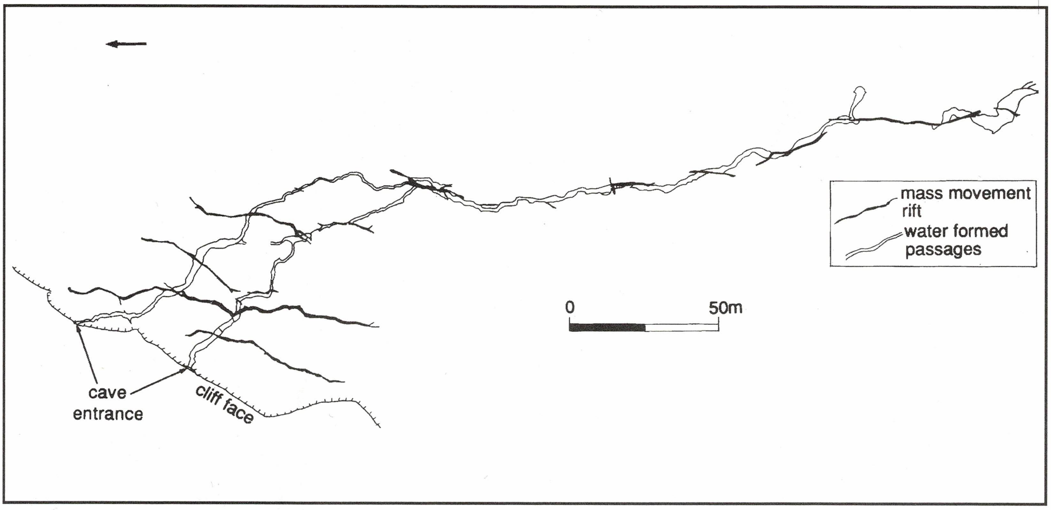

Fig. 2. Blacknor Hole: the two main types of passage.

It was with considerable surprise that early explorers in Blacknor Hole, wriggling in along the phreatic tube from the cliff face, found that it intersected a succession of vertical rifts, which were clearly neither phreatic nor vadose (Fig. 2). It was immediately obvious that the rifts were later than the phreatic tube because the phreatic tube continued on the opposite side of each vertical rift (Fig. 3). Therefore the caving problem in each case was to emerge from a hole halfway up the vertical wall of a rift, and then to insert oneself into the corresponding hole halfway up the vertical wall on the opposite side of the rift. It was apparent that in each case water from the phreatic tube had not flowed into the vertical rift, but had continued along the phreatic tube at a time when the rift was closed, or perhaps even at a time when the joint represented by the rift (which is a widened joint) had not only not opened, but did not exist. The latter possibility arises because of the putative great age of the water-formed caves on the Isle of Portland (Ford & Hooper, 1964; Graham & Ryder, 1983) which must have formed at a time when the Isle of Portland was part of a much more substantial landmass.

DISCUSSION

It appears that the Blacknor area of the Isle of Portland is subject to a form of cliff retreat, whereby large blocks of limestone ('towers' in cross section, Fig. 3) have moved westwards (or WNW, orthogonally to the general trend of the joints themselves). This has opened and widened pre-existing joints in their rear, severing the water-formed cave passages which they contain.

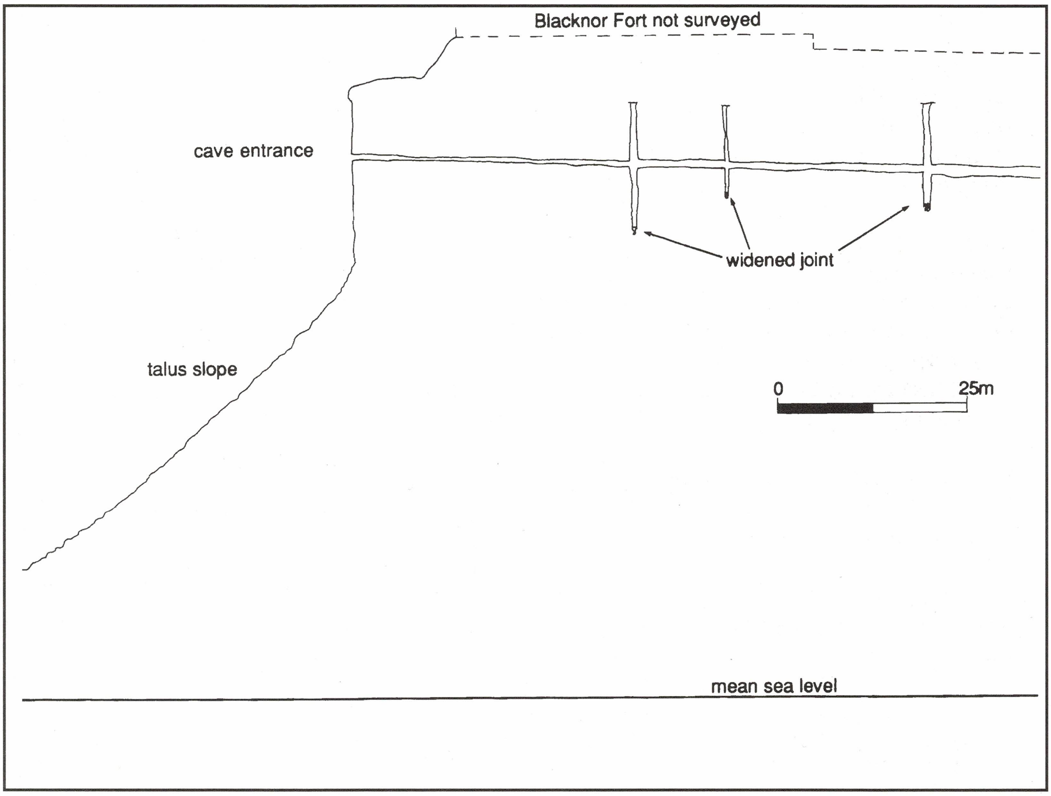

Fig. 3. Cross-section through the cliff at Blacknor.

This evidence from within Blacknor Hole confirms inferences made by Cooper & Solman (1983) from features found on the cliff face at Blacknor. Unusually, the cliff face at this point not only contains cave entrances, it also has patches of flowstone adhering to it. Flowstone is, of course, a characteristic speleothem , formed in the cave environment. When calcium carbonate is deposited on the landsurface, it usually takes the form of tufa, not flowstone. Furthermore, the flowstone deposits on the cliff face contain pebbles, cemented to the cliff face by the flowstone, 4 to 6 m above the present cliff foot at the head of the scree slope (see Fig. 3). A photograph of this is included in Cooper & Solman (1983). The inference made was that the cliff face itself is the eastern wall of a widened joint, the western wall and its limestone block ('tower') have collapsed down the scree slope.

Towards the foot of the scree slope, there are indeed some very large fragments of fallen limestone, slab shaped, and several metres thick. It is tempting to identify these with the hypothesised fallen slab, but there is no real evidence for this: the fallen slab, on its fall, may have disintegrated into small fragments, forming or covering the present scree surface.

At the very least, it can be suggested that the widening of NNE-SSW trending joints in the Isle of Portland has 'pushed' one large slab of limestone westwards to a point at which it has fallen. The way in

which it fell may be simply that it overbalanced due to lack of support from lower rock horizons which were not moved westwards in a similar way. This would require the lateral, westward movement to have taken place over a bedding plane in the effectively flat-lying rocks; as stated there is a slight southward dip, not a westward one. Alternatively, the rock slab may have fallen because the underlying stratum was not competent to support it. This would involve squeezing-out or squashing (compaction) of the underlying material.

Either way, there are two types of fall which could have taken place:

- the slab could have fallen as a result of tilting outwards, away from the eastern side of the widened joint, so that the widened joint became wider in its upper parts than in its lower parts. The fall of the slab would then be of the type known as toppling failure. The slab would probably break up into fragments on impact with the scree slope, with its upper parts further down the scree slope than its lower parts.

- Secondly, the slab could have fallen foot-first, its foot having started to slide outwards as incompetent material below gave way. It is likely that this would bring the head of the slab into contact with the eastern side of the widened joint, and as sliding of the base of the slab down the scree slope progressed, the angle of the back-tilted slab would increase. This could lead to the trailing edge of the head of the slab scraping down the eastern side of the widened joint. As this eastern side of the widened joint would become the new (present) cliff face, the cemented deposits adhering to it would have been scraped off by the trailing edge of the head of the falling slab.

  Since they have not been scraped off, this suggests that the toppling hypothesis may be the more likely of the two, although local variations in the plan shape of the cliff edge could probably protect certain areas from scraping in the circumstances described.

  Such explanations may be adduced for what seems to have happened at the cliff face, but other related matters remain unexplained. While joint widening behind the cliff face may be explained as part of a block-collapse process, the evidence at Blacknor does not tell us:

  - whether the inferred most recent block collapse (which may not in fact be recent at all) is part of a sequence or succession of such collapses, i.e. is there a characteristic cliff-retreat process going on at Blacknor?

  - while the existence of widened joints behind the cliff face may be due to some cliff-retreat process, this does not explain why apparently all the joints on the NNW-SSE orientation on the Isle of Purbeck are widened, even those in the centre of the Isle (Cooper, 1983a).

CONCLUSION

On the basis of the observations made, and in particular the ready classification of the various passage types encountered in Blacknor Hole, it is clear that there have been at least two distinct phases in the development of the caves in the Blacknor area of the Isle of Portland. The first phase was a period possibly dating as far back as the Tertiary (this would mean that the water-formed passages could have developed more than 2 million years ago). The second phase has been a period which is possibly still continuing, during which joints imparted to the limestone during the Alpine period of mountain building have been widened. In the Blacknor area, this seems to have facilitated a form of cliff retreat by successive block-collapse.

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